DRAFT THEMATIC PLAN
Isotope Hydrology in Groundwater Applications

Overall objective: *To contribute to high quality technical co-operation and build a wider constituency for the Agency's activities.*

Immediate objective: *To demonstrate the usefulness and potential impact of isotope techniques in efforts to solve priority development problems and for implementation of national plans and programmes, by integrating nuclear technology in Member States' water resource management.*

I. Development need addressed

The sustainable development and management of groundwater resources require an accurate assessment of its occurrence and availability. The sustainable development of a resource implies meeting the present needs without compromising the future availability. However, because of the urgent need to satisfy the present demand, financial constraints generally result in the exploitation of groundwater with a minimal, if at all any, quantity or quality assessment, often resulting in unwanted environmental consequences.

Some of the principal requirements for groundwater assessment include an understanding of the source and renewal rate of groundwater, the dynamics of the groundwater within aquifers, and the interconnections between shallow and deep aquifers. It is in these aspects of groundwater resource management that isotopic techniques add the greatest value. The use of isotopic techniques, most often together with traditional hydrologic tools, provides a rapid understanding of the groundwater systems on a large-scale at a relatively small cost.

Although various issues related to groundwater assessment and management exist, the experience obtained by IAEA from its research activities and field projects with Member States indicate that the following groups of specific problem areas are dominant:

a) Identification of recharge sources/processes, estimation of recharge rate

Reliable assessment of available groundwater resources is of primary concern for its sustainable development. Groundwater does not exist in isolation, but is an integral link in the hydrological cycle. One of the most important aspect for making a water balance of a given aquifer system, as a basis for determination of available water for abstraction, is the rate of replenishment (or recharge) from various sources. They are periodically replenished by precipitation and by surface water percolation down through the soil. Information on the source and process of replenishment, as well as its rate is essential for sound development and management. Reliable estimate of the replenishment rate from precipitation, particularly in arid regions, is rather difficult through indirect measurements of relevant parameters involved in the water balance.

b) Impacts due to *(over)*exploitation

Groundwater supplies are coming under increased pressure from growing human populations that consume increasing amounts of water as socio-economic development proceeds. As a consequence particularly in arid regions, groundwater reserves are being over-exploited at unsustainable rates. Over-abstraction causes a number of serious problems such as: reduction in yields from wells which ultimately increases the cost of pumping and thus price of urban water supplies; drying up of shallow wells which are subsequently abandoned because of falling water levels; land subsidence due to over-exploitation which is a major problem in many major cities; intrusion of salt water in coastal sites; and rising of saline water from deep or adjacent groundwater in response to pumping at inland sites; among others. Salinity levels from 1000 to 57,000 ppm of total dissolved solids have been encountered in major aquifers in the Middle East. FAO estimates that about 30 million ha of the presently irrigated area are severely affected by salinity and an additional 60-80 million ha are affected to some extent. UNEP recently reported that the rate of loss of irrigated land from water-logging and salinity is 1.5 million ha per year.

c) Mining of fossil groundwater reserves

Most of the major groundwater bodies in arid and semi-arid regions contain extremely old groundwater which are derived from rainfall that fell during more humid climatic conditions over the last 30 000 years. These groundwater bodies are termed fossil or paleo waters. The present abstractions from these reserves are "mining" the existing fossil waters. Despite the irreplaceability of this resource and the consequence of present abstractions, no importance has been allocated to reliably assess the areal extent of these water bodies.

d) Groundwater pollution

Groundwater is increasingly polluted due to agricultural practices as well as domestic and industrial waste water releases while rapid urbanisation contributes pollutants in a very complex way. The cost of remediating a polluted aquifer is very high while restoration to drinking water standards is often impossible. A critical weakness in attacking problems related to groundwater pollution is the need to understand the complex processes causing it, the spread of pollution, the need for appropriate management tools within a drainage basin framework and scarcity of data related to water quality.

e) Waste water re-use

Wastewater, whether treated or untreated, has recently been used either to intentionally artificially recharge aquifer systems or as a consequence of agricultural practices, inadvertently recharged shallow aquifers due to infiltration of water from agricultural areas. As substantial amount of waste water is being utilised, particularly for agricultural water supply purposes, the impact on the aquifer systems still remains to be carefully assessed.

II.Technical Solution

A variety of well-established and emerging isotopic techniques provide excellent means for obtaining the critical information required for the effective management of the groundwater resources as related to all of the above cited issues.

Methodologies based on the use of isotopes in a wide spectrum of hydrological problems encountered in water resources assessment, development and management activities are already an established scientific discipline recognised as **"Isotope Hydrology".** The methods have been proven and have long been employed as an integral part of water resources investigations and environmental studies. Together with techniques based on the use of radioactive isotopes for water tracing purposes and use of sealed radioactive sources for in-situ measurements related to water movement, they comprise the overall field of **"Nuclear Techniques in Hydrology".**

During the last four decades, the International Atomic Energy Agency (IAEA) has been directly involved in efforts towards research and development of nuclear techniques in water sciences, and their actual field applications, and has acted as an international-scale focal point for dissemination of information and promoting their wider-scale use, within the framework of its activities related to peaceful nuclear applications.

The potential role and contributions of isotope methods in the water resources sector can be grouped into the following general categories:

- Determination of physical parameters related to flow, its dynamics and structure of the hydrological system;
- Process tracing relating to delineation of processes involved in circulation of water and mass transport of dissolved constituents;
- Identification of origin (genesis) of water;
- Component tracing through determination of pathways and mixing ratios of component flows; and
- Study of "time-scale" of hydrological events.

"Isotope Hydrology" deals with various methodologies essentially based on the general concept of "tracing", in which either naturally occurring isotopic species (environmental isotopes) or intentionally introduced isotopes (stable or radioactive) are employed. The use of naturally occurring isotopes, often referred to as "Environmental Isotope Methodologies", has the distinct advantage of facilitating the study of water movement and hydrological processes on much larger temporal/spatial scales than possible with intentionally injected tracers, which are often used for site-specific, local-scale engineering problems. The production and temporal/spatial variations of environmental isotopes in the hydrological cycle cannot be controlled by the investigator, and they are the result of different natural processes. However, hydrological inferences can be made through observations of their concentration distribution in a given hydrological system. Therefore, environmental isotope methodologies are unique in regional-scale applications in water resources, while use of radioisotopes as tracers are often related to local scale applications.

Isotope techniques have successfully addressed the different emergent development issues in water resources assessment and management in the different field projects of the IAEA. In most cases, isotopes provide a qualitative (QL) definition or solution of the hydrological problem while in certain circumstances, quantification (QN) of hydrological parameters are enabled only by the application of these methodologies. These development issues where isotopes are indispensable are summarised below:

DEVELOPMENT ISSUES IN WATER RESOURCES

I. FOR IMPROVING WATER RESOURCE ASSESSMENT

1. Natural Recharge/Discharge- as an input to estimates of water balance

With isotope techniques, it is possible to:

- Determine the sources and area of recharge *(essential for water balance and water availability)*-QL
- Determine processes of recharge *(how recharge take place and its dynamics)*-QL
- Estimate the rate of the recharge-QN
- Estimate the rate of diffused discharge-QN

2. Fossil/Paleowaters - commonly encountered in arid zones

With isotope techniques, it is possible to:

- Map (occurrence) particularly for transboundary aquifers-QL
- Improve assessment of the hydraulic relation to adjacent surface/groundwater water bodies - QL/QN
- Estimate available resources-QN

3. Verification of Water Balance through groundwater flow modelling - QN

Isotopes would provide a confirmation of the observations obtained from traditional hydrological investigations

II. FOR GROUNDWATER MANAGEMENT ISSUES - associated with the effects of man's activities or anthropogenic impacts

1. Groundwater Pollution

With isotope techniques, it is possible to:

- Identify some specific sources and processes - QL
  ⇒ *(e.g., geochemical and biological sources)*
- Establish pollutant transport patterns and dynamics and estimate relevant parameters-QL/QN
- Validate/calibrate pollutant transport models - QL/QN
- Assess aquifer vulnerability to pollution as decision-support system - QL/QN
  ⇒ in densely populated urban areas *(megacities)*- QL

2. (Over)exploitation

With isotope techniques, it is possible to:

- Assess groundwater salinization - QL/QN
  * seawater encroachment in coastal zones
  * groundwater mining
- Assess induced adverse effects due to exploitation - QL/QN
  ⇒ *(e.g., inter-aquifer mixing or inflow from other adjacent sources)*

3. Artificial recharge of groundwater

With isotope techniques, it is possible to:

- Assess the effectiveness of different schemes as a means of improving water availability - QL
- Identify the most suitable sites considering hydrogeological conditions - QL

4. Impact of wastewater re-use on groundwater resources - QL/QN

III. Description of the sub-sector

The availability of freshwater is one of the great issues facing mankind today, because problems associated with it affect the lives of many millions of people, and the issue has attracted a wide scale international attention by UN Agencies and related international/regional governmental and non-governmental organisations. Availability of freshwater resource is also affected by quality. In 1990, 1.2 billion people, or 20% of world population, did not have a safe supply of water, and about 50% of the population had inadequate sanitation. A recent UN report states that more than 5 million people die annually just from disease caused by unsafe drinking water and lack of sanitation and water for hygiene.

The issue of availability and quality of water resource is directly related to the rising global demand for water. Demand is estimated to have risen six to seven times from 1900 to 1995, more than double the rate of population growth. It is a rise which seems likely to accelerate into future, because the world population is expected to reach 8.3 billion by the year 2025 and 10 to 12 billion by 2050. Total global water withdrawal at the present (1995) comprises some 3750 cubic kms/annum, with actual consumption at some 2270 cubic kms/annum (61% of withdrawal). In the future, total water withdrawal will grow by about 10-12% every ten years, and by 2025 it will reach approximately 5100 cubic kms/annum, a 40% increase. The volumes of water withdrawal are very unevenly distributed throughout the continents and in no way match the volumes or distribution of water available.

The project growth in demand linked with increasing agricultural requirements. At present, agriculture receives 67% of total water withdrawal and accounts for 86% of water consumption. The global irrigated area was 254 million ha in 1995. By 2010 it is expected to grow to about 290 million ha and by 2025 to 330 million ha. By the year 2025 agricultural water demand is expected to increase by 30%, along with a 50% growth in industrial demand and global demand for public water supplies.

Projections of population growth and future water demand indicate that by the year 2025 water scarce areas, where supply cannot meet demand, will exist over substantial portions of northern and eastern Africa and western Asia.

The importance of groundwater

Groundwater accounts for over 95% of the Earth's available freshwater and plays an important role in maintaining soil moisture, stream flow, and wetlands ecosystems. From the human perspective, groundwater is a vital source, particularly in arid and semi-arid regions and on islands, where it is often the only freshwater available. At present, at least 1500 million people depend on groundwater for their primary drinking water supply.

Groundwater has numerous advantages over surface water resources. First, its supplies are not subject to abrupt change as a result of abnormal short-term climatological conditions. Secondly, groundwater has self-purification process under natural conditions and often requires no treatment before use. It can be developed stage by stage requiring comparatively less initial investment as compared to surface water storage schemes. Thirdly, groundwater can be often tapped near to where it is needed while surface water must either be developed at the sites of natural dams or reservoirs, or piped considerable distances to where it will eventually be used. On the other hand, since it is not directly accessible, required data and investigations for proper assessment and development of groundwater is more complex and costly.

IV. Strategic approach/Modalities

Isotope hydrology projects generally require multi-disciplinary approaches and, therefore, a strong co-ordination as well as commitment on the national level. A key to identifying national priorities in groundwater resources assessment and management is by analysing planned and on-going large scale projects on water resources assessment or water supply augmentation. The specific problems within these projects, where isotopes provide the necessary information either as indispensable or cost-effective tools, represent the areas where the highest impact can be achieved.

The identification of problem areas for isotope application in national priorities may be achieved by several means. Due to the multitude of institutions involved in the Water Sector and the need for interdisciplinary solutions to problems, it is recommended that two mechanisms should be emphasised in the process of developing Country Programme Frameworks involving Water Resource Management. These are:

(1) holding national and regional workshops involving relevant stakeholders among technical as well as water management institutions to discuss the water resources development and management activities and identify needs and applicability of isotope techniques, and
(2) analysing the national priorities in water resources development as evidenced by large scale projects where national and/or international funding is being channelled.

Identification of Counterpart Institutions

Many national institutions are involved in the water resources area in a given country. An appropriate institutional framework on the level of the recipient country is critical for the success and sustainability of TC projects. This requires that the project counterpart institutions should have substantive roles and responsibilities in the water resources area. These may include institutions responsible for the assessment of water resources, development or exploitation of water resources, water supply to urban and rural areas, monitoring of water quality, etc. The institutional structures differ between countries depending upon the socio-political structure, history of institutional development, specific needs, etc.

Comprehensive water resources assessment and management at the watershed or basin scale are organised by building centralised basin management organisations. The exploitation and management of groundwater, on the other hand, generally occurs on a local scale and the institutions responsible for this activity may include a water supply authority or city government. However, the nuclear technology institutions, such as Atomic Energy Authorities or Universities, generally are separated from these water resources institutions.

It is recommended, therefore, whenever possible, to involve both science and technology institutes, end-users and other stakeholders in pre-project planning and project formulation. If possible, multiple counterparts should be used for a TC project. To maximise the benefits from the isotope hydrology projects, the Agency should also serve as a catalyst and to enhance the co-ordination between the respective institutions. This co-ordination may be formalised by encouraging governments to develop a network of participating organisations, and to assign a national focal point responsible for ensuring proper linkages on the country level.

Impact Assessment

The impact of isotope hydrology projects on water resources development and management in a country should be assessed with care, not only after the completion of a project, but in pre-project planning and project formulation. For this purpose, it should be recognised that there may be both short-term and/or long-term impacts from the use of isotope hydrology techniques. The TC programme should be guided by opportunities where the use of isotope hydrology techniques may be indispensable or cost-effective compared to other techniques in the alleviation or a current problem. These may include, for example, the determination of the renewable or non-renewable nature of the resource, the quantification of the recharge rate of an aquifer, and the delineation of flow patterns of aquifers. On the other hand, it must be understood that studies which feed in to long-term management planning etc. will not result in visible impact in the short term.

V. Limitations

Regional Centres

The IAEA General Conference has expressed support to the concept of letting lead centres to facilitate and enhance technical and scientific co-operation among developing countries. Embedded in this request is the basic belief that Developing Countries benefit from pooling their resources. Moreover, the effectiveness and efficiency of technical co-operation is enhanced through TCDC and through greater reliance of viable centres within regions. This notion is also reflected in the TC Strategy according to which the Agency intends to strengthen regional co-operation by encouraging the more advance national institute within regions to contribute fully to solving problems within the region. Thematic plans support this objective by helping to establish opportunities for technical co-operation among developing countries.

The use of regional centres are particularly important in the case of groundwater assessments and management, due to the transboundary nature of the problem and the similarity between problems experiences in countries and regions. In keeping with this notion, the Agency will encouraged the use of key centres to perform analytical backstopping of projects within regions. When it is necessary to generate scientific data for addressing a relevant development problems, TC will consider existing analytical capabilities within a region, before introducing new technology. This will lead to the thrifty use of scarce resources through the increased use of past investments by the Agency and by Governments. In addition, encouraging the use of viable analytical centres will contribute to he sustainability of isotope hydrology applications within regions and to TCDC.

Based upon these discussions and the General Conference Resolution, the TC Department will request the Hydrology Section to recommend a specific set of criteria for identifying more advanced institutions within regions capable of providing technical support, implementation services and reference/skill development in isotope hydrology. These will be vetted through regional mechanisms as outlined in the Technical Co-operation Report for 1997, approved by the Board in June 1998.

Least Developed Countries (LDCs)

One important function of the use of centres-of-excellence is to encourage co-operation between more advanced with less advanced countries within regions. In connection with LDCs, a recent SAGTAC report pointed to the paramount importance of exploration and development of underground water resources and the crucial role to be played by isotope hydrology. It is therefore important to consider the special situation prevailing in LDCs. Special forms of assistance may be called for to sustain the integration of isotope hydrology in water resource assessments and management in such countries. In identifying problems, counterparts and partners in LDCs, the Agency should also consider the important role of bilateral and multilateral programmes in LDCs, where national plans and programmes are often sustained through international development co-operation.

Introduction of isotope hydrology in University teaching

The General Conference has requested the Agency to take steps, along with other relevant UN Agencies, to introduce, at appropriate levels at universities in Member States, courses in hydrology designed to provide future hydrologists with an early insight into the potential of isotope techniques. The integration of isotope hydrology in to university curricula is recognised as an important means towards the long-term implementation of the thematic planning objectives. RIPC, through its co-operation with UNESCO, will be spearheading the efforts to address this issue, and TC will consider it, as applicable, in the design of its projects.

Co-operation with international organisations and development programmes

The IAEA Board has endorsed a strategy for TC which, among other elements, features the concept of expanding the impact of project outputs and outcomes through partnerships with key organisations in the field. The objective seeks to ensure that project results reach end-users and sustain impact in the given field of activity. The Agency's strength is it's technical excellence, but it's challenge in fields involving of isotopic and radiation applications is to demonstrate the usefulness and impact of these techniques in social economic development. Partnerships with governmental, intergovernmental and non-governmental international organisations are therefor instrumental for bringing Agency project results to the end-users.

The Agency has long standing and well functioning links with other organisations in the water sector at the policy and research levels. In contrast, relatively few linkages have been forged at the field level.

Recent steps through the Agency's joint activities with UNESCO's International Hydrological Programme (IHP) programme have demonstrated to several water authorities and development partners in the field that isotope hydrology can play a the significance role in strengthening water management, particularly the priority water problems mentioned earlier. In Africa, regional project formulation activities in the sector have taken place in the field through workshops that included national water authorities and some international organisations.

It is the sense of these consultations that this process should be expanded and further that the function of programme co-ordination in the water sector should be project -specific. Co-ordination should be field-based. It is recognised that the role of the IAEA's programme in the water sector is to improve the accuracy and reliability of data for water resource assessment and expand the knowledge base for water management. It is also recognised that the outcomes from many Agency TC activities have great value to funding organisations investing in water resource development and management projects through grant and concessional aid.

Examples of projects of programmes which could benefit from the integration of isotope techniques include:

- A GEF project to develop a "Strategic Action Programme for Integrated Management of the Okavango River Basin"
- World Bank financed projects in water resources management in Mexico, Morocco and Brazil;
- World bank salinity studies in the Nam-Mekong Delta of Vietnam; artificial recharge in Yemen; pollution control in Brazil, China, Egypt and Peru

In these examples, national water authorities, finance ministries, the World Bank, GEF and other funding organisations are "end-users" of Agency projects in the field. Linking IAEA water assessment project outputs to decision making mechanisms in development projects of other organisations is a key programme management activity that should be prioritised. As the value of isotopic investigations to public/private investment in the water sector becomes fully accepted, these funding organisations could play a greater role in financing activities where critical data or management experience is required to establish the feasibility of an activity or improve decision making for resource management.

It is recommended that the 1998 management review of operational functions and responsibilities consider possibilities for rationalising the project management functions in order to provide opportunity time for country officers to undertake necessary programme reviews in the water sector and to actively pursue the linkages suggested. In this context, programme development as a strategic function to support TC Objectives should be included in the job description for country officers.

Problem of Groundwater Assessment/Management	Objectives of Isotope Techniques Study	Framev		
		Ongoing/Planned Activities	Data Available	
Improving Water Resources Assessment				
Recharge/Discharge	Estimation of rates	Short-term/long-term projects	Yes/No	W Hy us
Fossil/Paleowaters	Groundwater dating/estimation of flow rate	" "	" "	"
Water Balance	Rate of recharge/discharge	" "	" "	"
Groundwater Management Issues				
Groundwater Pollution	Sources and processes/transports	" "	" "	W Hy
Over-exploitation	Sea-water intrusion/mixing of aquifer	" "	" "	W
Artificial Recharge	Assessment of effectiveness	" "	" "	W us